

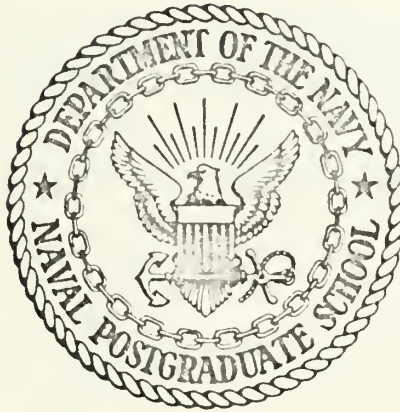
AN INVESTIGATION OF THE INVENTORY POLICIES
OF A SMALL PRODUCTION FIRM

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NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

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OF A

SMALL PRODUCTION FIRM

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of a
Small Production Firm

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ABSTRACT

A study was conducted of the inventory operations of a small production plant. Based on parameters established or estimated during the study, a simple inventory model which yields stock levels for the raw material inventory and production quantities for the manufacturing operation was developed. Price comparisons were made showing the recommended policies to be more economical than those policies used before the study was conducted. A search routine proffered by Buffa and Taubert was examined and shown not to be acceptable as a method of determining production quantities for the company investigated.

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I. INTRODUCTION

A small manufacturing organization just as large corporations must make a myriad of inventory decisions in its daily operations. In a small organization these decisions may have a far greater impact on profit than do the identical decisions in a large firm. The decision and information flow and thus some degree of rationale is usually more readily evident in a smaller concern than in its larger cousin. Thus the inventory problem is often relatively more important, but at the same time easier to investigate in depth. Of course, the same principles are involved in both large and small operations; and findings from a study of a smaller system are readily adaptable to large systems -- even to an operation as large as the Department of Defense supply organization.

An inventory study was conducted at a small plant which produces self-propelled and non-self-propelled (i.e. trailers) cargo handling equipment. Since information of a proprietary nature was used in this study, it is felt that this material and information should be protected from disclosure to competing firms. Consequently, the production plant studied will, when necessary, be referred to simply as "The Company", and the products as models A, B, C, etc.

The Company maintains a spare part inventory which will be called "raw material" to provide direct support for the production effort; and to provide an immediately available source of parts for "parts sales" to customers who require

replacement of parts for previously purchased equipment. Annual part sales have been one million dollars while annual sales from their production effort has been approximately ten million dollars. At the time the study was conducted, the value of "raw materials" to support these sales was \$1.45 million. This inventory had been reduced from \$3.0 million the preceeding year because of continuing and subjective pressure from higher management in the parent firm. The reduction appears to be an over-reaction to high overhead costs. Coincident with this higher management pressure to reduce inventory levels, this writer was asked to investigate Company inventory policies in order to formalize a method of controlling the raw material and finished product inventories.

A second area of the inventory study concerned the equipments produced for stock. The Company produces twenty-three distinctly different items, many of which have a very low demand (in the order of two demands per year, or less) thus reducing any interest in maintaining a stock of those items. In addition, many of the items have a multitude of options that are available to the customer and must be built into the equipment during production. This factor could be likened to an automotive assembly line which produces many varieties of one type of automobile. This option problem as it relates to production is recognized as a fertile area for further study (i.e., expected options or expected sales, how they should effect the percent completion and the number

of the items to be produced strictly for stock). In view of the time limitations met in conducting this study, these models containing the various "built-in" options are not considered. However, four production items which are built either without options or with options that may be installed in the final steps of production (as the color of finish or size of tires in the production of automobiles) were considered. It should be noted, that most of the methods and principles used in discussing the four items in this paper would also apply to the other items produced by The Company.

II. DEVELOPING AN INVENTORY POLICY FOR PRODUCTION ITEMS

The present policy of The Company is to begin production of the item in the quantity of the order only after receiving a confirmed order for an item. Although that policy eliminates all holding costs of the production items, it forces a delay in satisfying all demands, it tends to maximize total set-up costs, and it prevents the planning of manpower resources in the production department.

Management personnel of The Company are not familiar with mathematical modeling techniques. There are sophisticated stochastic models of the production inventory process which have the benefits of providing a more nearly accurate representation of the actual operation. However, the problem of communicating their results, recommendations, and justifications take on an inordinate level of difficulty and thus lessen the confidence of the analyst in the eyes of management. If one assumes a continuous demand and constant demand rate, unit production costs that are not a function of the quantity produced (i.e. no learning is experienced during a production run), a constant production set-up cost independent of the size of the production quantity, and a holding cost rate solely dependent on the item cost, a simple model can be developed which utilizes an easy to follow logic flow (See chapter 2 of ref. 1). Since no quantitative analysis in this area had ever been attempted for The Company, even this simple model would provide a discernable step

towards reducing the costs of the operation. For this reason, the simple model was eventually settled upon to approximate the inventory operation. Further refinements, not only in demand and lead time distributions but in improving the accuracy of the parameters (holding cost rate, etc.) are recognized as worthy of further study. More will be said concerning parameter estimation later in this paper.

A. SET-UP AND UNIT COSTS

There is a cost connected with preparing the production line for full production. This is known as the "set-up" cost. A cost over and above the set-up cost, the unit cost must also be investigated. The set-up cost is primarily the labor cost (including base pay and benefits) of bringing the jigs and dies to the assembly line, clearing the production line for work, and positioning material. Since the cost of the jigs and dies are very small, the amortization costs were not considered.

Although The Company has an Industrial Engineering Division, it was not able to provide any direct measure of set-up costs. A partial list of detailed production function operator times and the related set-up times for only one of the four equipments under consideration was available. This information was used in a first attempt to establish set-up costs. This information, however, was found to be incomplete and judged unsuitable and too misleading to consider.

The Industrial Engineering Division has made the assumption that production operations are learned at a 95% rate. That is, when Q items are produced, the average cost of each of them, L_Q , is $.95^x$ times the cost of the item if only one were produced; where $x = \log_2 (Q)$. The assumption infers that each time production of a particular item starts, no learning from previous production runs of this item exists. The Industrial Engineering Department feels that since production workers are employed in manufacturing a wide variety of finished products and may not return to production of a previous item for a relatively long time, the carry-over of learning from one production run of the item to its next production run would be small.

In general, learning rates are applicable to operations (production of a particular item) and not to an individual or group (as a production division). Therefore, a constant learning rate, as in this case 95%, is not necessarily a valid assumption -- although it may approximate a median learning rate of the combined operations.

Recorded production costs for each order were available and were used in determining the total cost for each production run. Because of gross changes in production practices which occurred, no cost data over two years old was considered. The number of units made in the production run was also recorded. The following equations in two unknowns, A (set-up cost), and C (unit production cost, excluding set-up costs) were used to attempt to determine the two parameters:

$$T = (QL_Q C) + A$$

where T = total recorded price for the production run

CL_Q = average unit cost for producing Q items

Q = number of items produced.

An example of a plot of total cost of a production run vs. quantity produced is shown in figure 1.

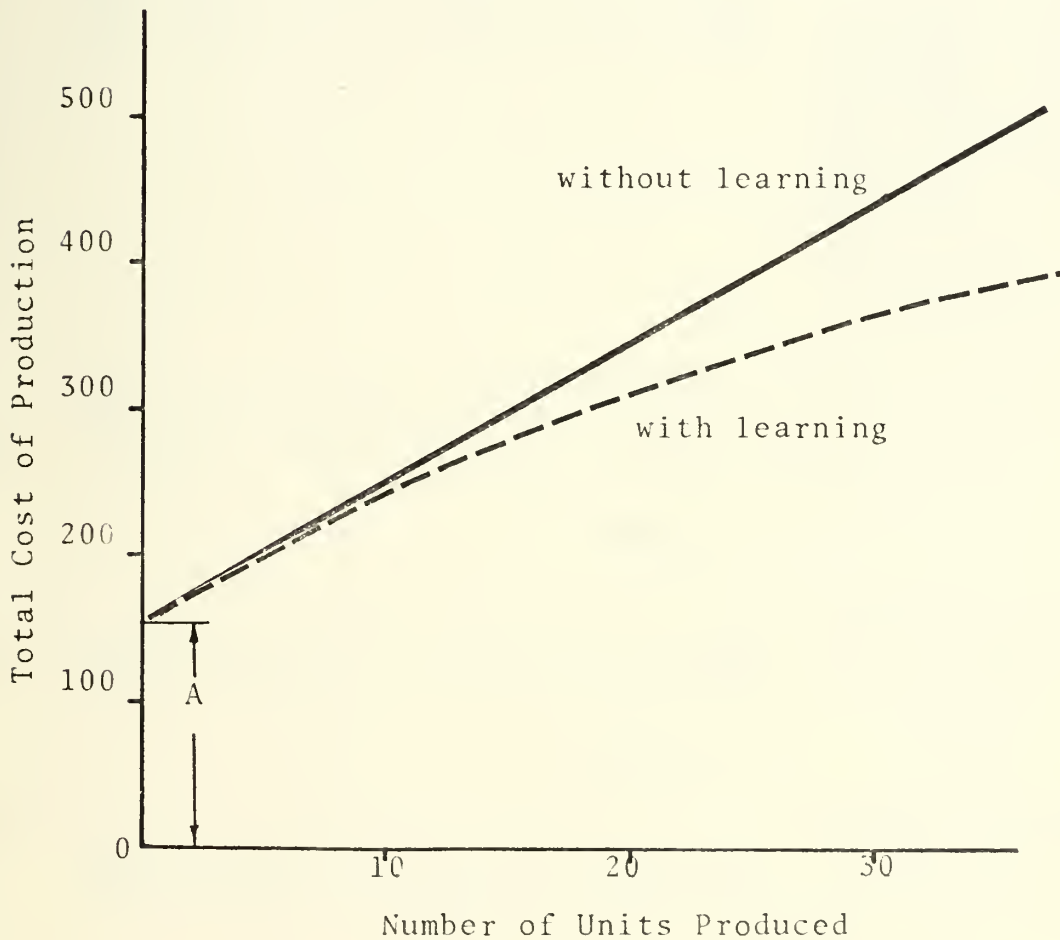


Fig. 1

The data points and computed parameters are displayed below for each model:

MODEL A

		computed parameters
data point 1:	Q = 25; T = \$179,400	
data point 2:	Q = 50; T = \$267,450	C=\$2325; A=\$133,876

MODEL B

		computed parameters
data point 1:	Q = 9; T = \$ 9,882	
data point 2:	Q = 30; T = \$ 21,540	C ₁₂ =\$742; A ₁₂ =\$4232
data point 3:	Q = 35; T = \$ 22,925	C ₁₃ =\$667; A ₁₃ =\$4692
data point 4:	Q = 12; T = \$ 11,736	C ₁₄ =\$803; A ₁₄ =\$3736
		C ₂₃ =\$390; A ₂₃ =\$12,440
		C ₂₄ =\$735; A ₂₄ =\$4316
		C ₃₄ =\$415; A ₃₄ =\$7606
		The means of the C _{ij} 's
		and the A _{ij} 's were ^{ij}
		computed
		as:
		\bar{C} =\$627; \bar{A} =\$6171

note: A_{ij} and C_{ij} are the computed A and C using data points i and j. Also C_{ij} = C_{ji}; and A_{ij} = A_{ji}.

MODEL C

		computed parameters
data point 1:	Q = 1; T = \$ 13,672	
data point 2:	Q = 6; T = \$ 68,928	C = \$12,980; A=\$692

MODEL D

		computed parameters
data point 1:	Q = 1; T = \$ 25,599	
data point 2:	Q = 10; T = \$179,627	C = \$20,750; A=\$4849

The computed set-up costs in three instances were greatly different from those costs the management of The Company considered reasonable. The logic that The Company management used in arriving at their range of set-up costs seemed sound -- particularly when considering the simplicity of some of the items. The large discrepancy can be accounted to the manner in which the total costs of the production runs were accumulated. It is felt that inaccurate cost recording, particularly labor costs, and the restarting of production runs (i.e. a production run recorded as a single run of ten items may have been stopped and restarted several times thus incurring additional set-up costs which were not considered but were included in the total production costs) greatly distorted the accuracy and worth of the accumulated data.

No additional information was available to more accurately determine either set-up costs, unit costs, or learning rates.

A study with its attendant recommendations no matter how expertly carried out is worth nothing if its recommendations, if worthwhile, are not implemented. As a result of this, and being unable to prove or at least to adequately infer set-up and unit costs from the two attempts previously described, the costs used were those approximated by the Industrial Engineering Division and agreed upon as realistic estimates by the management of The Company. The set-up and unit costs used are as follows:

<u>MODEL</u>	<u>SET-UP COST</u>	<u>UNIT COST</u> (exclusive of set-up)
A	\$ 1200	\$ 5500
B	\$ 57	\$ 800
C	\$ 2340	\$ 12200
D	\$ 3000	\$ 20600

B. PRODUCTION RATE

The production rates were measured from recent historical data assuming no major material delays and average conditions and found to have the following values:

<u>MODEL</u>	<u>PRODUCTION RATE</u>
A	5 per week
B	20 per week
C	1 per week
D	1 per week for production runs less than five; 1.5 per week for production runs between five and ten; and 2 per week for production runs greater than ten.

note: The change in production run for model D is due to increased number of personnel normally assigned to the production effort as the production quantity is increased.

During the course of this study, the Production Manager often expressed his desires that the study not only provide a basis for making inventory control decisions but also provide methods that his employees may easily use to update the results as certain parameters change. A finite production rate does not lend itself to a simple updating procedure. Since this analysis was the first study made for The Company, ease of using the results was an important consideration. Furthermore, because of the fact that customers do not expect

immediate delivery of the products that they order, the actual production rate is not a critical parameter. In addition, the assumption of infinite production rates results in lower (i.e. conservative) economic production quantities - thus conforming with the general Company trend toward inventory reduction. As a result, it was decided to assume infinite production rates throughout the study.

C. DEMAND

Another parameter in the inventory model that must be considered is demand or expected demand. The Company's Sales Division prepares a listing of potential customers for the following twelve months. The sales predictions indicate the items and quantities, B_i , for which each customer is interested. In addition, the Sales Division estimates the probability, P_i , of making each sale. This is done for each customer, i . The expected sales of each item is the sum of the expected sales for each customer (i.e. $\sum_{\text{all } i} B_i P_i$).

The economic production quantity of all equipments herein considered is a direct function of expected sales, and accurate sales forecasting takes on a high degree of importance. Since expected sales was the only forecast data available and represented The Company's best effort in this area, they were assumed to be within acceptable bounds of accuracy.

The nature of the items under consideration is such that the customers anticipate a delay before their orders will be

received. Because of this, it can be assumed that backorder costs are zero as long as the item is delivered within an expected production lead time plus delivery time. If The Company were to stock production products based on anticipated demands, they would be able to provide more rapid response to customer's orders. How this additional service would result in increased sales ; how the stocked items might affect sales promotions; and how impulse buying might increase sales can only be considered an additional but unaccountable benefit from this study. In fact, this area itself is a field worthy of a separate study.

D. PERIODIC REVIEW AND THE SEARCH DECISION RULE

In the initial attempt to provide management with a method to decide on a policy to govern production, a dynamic periodic review model was developed. Since The Company has forecasts of the next four quarters of demands and no back-order costs are suffered provided all demands are filled within a reasonable amount of time, the following assumptions were made:

(1) The demands in the next four quarters are known to be F_{i1} , F_{i2} , F_{i3} , F_{i4} where F_{ij} is the forecast of the total sales of model i in quarter j .

(2) Each production run commences at the beginning of the quarter and will be completed before the beginning of the next quarter regardless of the amount produced.

(3) The startup cost for each production run for Model i is A_i , independent of the quantity to be produced.

(4) The holding cost in quarter j for model i is $I_i C_i S_{ij}$ where I_i is the annual holding cost rate for model i , C_i is the unit cost of model i and S_{ij} is the average value of the on-hand inventory of model i in quarter j .

(5) All demands must be satisfied within the quarter.

(6) The total cost of producing Q_{ij} units of item i in quarter j is $A_i \delta_{ij} + C_i Q_{ij}$ where $\delta_{ij} = \begin{cases} 0 & \text{if } Q_{ij} = 0 \\ 1 & \text{if } Q_{ij} > 0 \end{cases}$. The objective is to determine, for each item i and quarter j , that quantity $Q_{ij} \geq 0$ to produce in order to minimize total production and holding costs subject to the constraint that all demands be satisfied within a quarter. Let N_{ij} be on-hand inventory for item i at the beginning of quarter j .

Then the problem can be written:

$$(1) \min_{Q_{ij}} K = \sum_{i=A}^D \sum_{j=1}^4 (A_i \delta_{ij} + C_i Q_{ij} + I_i C_i S_{ij})$$

subject to $N_{ij} + Q_{ij} \geq F_{ij}$ for $i=A,B,C,D$
and $j=1,2,3,4$

note: The inclusion of the term $A_i \delta_{ij}$ causes
the program to fail to be linear.

To solve this production planning problem an approach proffered by E. Buffa and W. Taubert (ref. 2) which is presently enjoying widespread attention was considered. Their approach, called the Search Decision Rule, SDR, attempts to solve aggregate planning problems through the use of optimum-seeking computer search methods. The heart of the Search Decision Rule is the computer search routine provided by Buffa and Taubert. To use this technique, a computer program was written which provides initial conditions, bounds on the

decision variables, and a function which determines the cost for any set of values of the decision variables. In order to handle the stockout constraint, the penalty function approach was used. In particular, each time $F_{ij} > N_{ij} + Q_{ij}$, a penalty function of 10^9 dollars was added to the value of equation (1). This quantity is of such magnitude that in minimizing costs, the constraint would never be violated. Beginning with the input values for the decision variables, SDR, the search subroutine, calculates the value of the objective function and then attempts to decrease this value by modifying the decision variables. This process continues until the search subroutine fails to recognize an improvement in the value of the objective function. The last set of values of the decision variables represents the recommended production quantities. As with any search technique, SDR does not guarantee optimality but it is expected that the values obtained provide at least a local minimum.

The Search Decision Rule was tested several times using actual Company data. In many of the cases a simple visual inspection revealed that the results could be improved. This was felt to be a result of the initial conditions. Therefore several sets of initial conditions were examined and the results indicated that the search technique is overly sensitive to the initial values. In fact, the technique is so severely sensitive to the initial values that it was judged to be inadequate for solving the production planning problem.

After rejecting the Buffa-Taubert technique as a tool for obtaining optimal values for the periodic review model; dynamic programming was considered. Note that the objective function is separable in the sense that it is the sum of the costs incurred for each of the four models. Define $Z_{in}(\xi_i, Q_{in})$ to be the minimum cost over the first n quarters of operation for model i when the on-hand inventory at the end of quarter n is ξ_i and the quantity produced is Q_{in} . Then let

$$Z_{in}(\xi_i) = \min_{Q_{in} \geq 0} Z_{in}(\xi_i, Q_{in}).$$

The following recursive relation is derived:

$$(2) \quad Z_{in}(\xi_i) = \min_{Q_{in} \geq 0} \{ A_i \delta_{in} + C_i Q_{in} + I_i C_i [\xi_i + \frac{F_{in} - Q_{in}}{2}] + Z_{i,n-1}(\xi_i - Q_{in} + F_{in}) \}$$

It was observed that equation (2) is the same as that developed by Hadley and Whitin in Section 7-4 of ref. 1. They develop a simple algorithm for determining the values of the decision variables which are optimal. The algorithm shows that the optimal production quantity for any quarter is always an integral number of future quarters demand. For example, if $n = 3$, $Q_{i3}^* = 0$ or F_{i3} or $F_{i3} + F_{i4}$. The optimal value is selected by considering the holding costs and set-up costs over this small range of alternatives.

These results were applied with the parameters previously discussed, and the actual Company forecasts for a four quarter period. The optimal production quantities for each

of the models over the four quarter planning horizon were calculated for a range of reasonable values of the holding cost rate. In each case, the production quantities were found to be those values which satisfy only the current quarterly demand.

This approach shows that forecasts of demand for quarters other than the current quarter are not important in determining the current production quantity. Since it only allows production at the beginning of each quarter, it seems possible the costs could be reduced even more if production were allowed at any time within the quarter. In order to examine this possibility a continuous review model is considered.

E. HOLDING COSTS AND ECONOMIC PRODUCTION QUANTITY

Holding cost consists of those costs which are related to keeping material in stock. It includes such items as wages of personnel related to receiving, storing, and issuing the material, the cost of money tied up in the inventory, rental of buildings, etc. used for holding inventory, taxes directly charged on the inventory value, and deterioration and obsolescence of the material kept in inventory. Those factors of holding costs caused by product deterioration during periods of unprotected outside storage, and obsolescence of the item as the industry needs vary are considered to be substantial and yet are very nebulous to price. It is usually the experience in a study of this type that

company's management feels it can adequately estimate holding cost. Therefore a matrix, one for each item under study, was developed which enables management to adapt to changing holding costs and presents a set of alternatives for management to choose among. The columns are a range of reasonable holding cost rates (in percentages). Management may select the most "reasonable" holding cost rate. This decision determines a row and therefore also a production quantity, Q , which is read from the left-hand column. In computing the production quantity, it was assumed that the demands were deterministic and known with annual rate λ , the set-up costs, A , were constant, no back orders were allowed, production rate was infinite, unit cost, C , is independent of quantity produced, and the holding cost was a function only of inventory value and accrued at an annual rate, I . The total annual cost, K , is as follows:

$$K = \frac{A\lambda}{Q} + \frac{ICQ}{2} + CQ$$

Considering only integer production quantities, Q , the minimum cost is achieved when

$$Q(Q-1) = \frac{2A\lambda}{IC}$$

It was the method that was used to determine the production quantity for models A,B,C, and D. The unit and set-up costs for each unit is given in section A of this paper. The results of these computations appear as tables I,II,III and IV immediately following this section.

PRODUCTION TABLE FOR MODEL A

ANNUAL DEMAND

Q	2	4	5	10	15	20	25	30	35	40	50	60	70
1	-	-	-	-	-	-	-	-	-	-	-	-	-
2	43.6	87.2	109	218	327	436	546	655	764	872	1091	1309	1527
3	14.5	29.1	36.4	72.7	109	145	182	218	254	291	364	436	509
4	7.3	14.6	18.2	36.4	54.6	72.6	91.0	109	127	146	182	218	255
5	4.4	8.7	10.9	21.8	32.7	43.6	54.5	65.4	76.3	87.2	109	131	153
6	2.9	5.8	7.3	14.6	21.8	29.1	36.4	43.6	50.9	58.2	72.3	87.3	101.8
7	2.1	4.2	5.2	10.4	15.6	20.8	26.0	31.2	36.4	41.6	51.9	62.3	72.7
8	1.6	3.1	3.9	7.8	11.7	15.6	19.5	23.4	27.3	31.2	39.0	46.8	54.5
9	1.2	2.4	3.0	6.1	9.1	12.1	15.2	18.2	21.2	24.2	30.3	36.4	42.4
10	1.0	1.9	2.4	4.8	7.3	9.7	12.1	14.5	17.0	19.4	24.2	29.1	33.9
11	.8	1.6	2.0	4.0	5.6	7.9	9.9	11.9	13.9	15.9	19.8	23.8	27.8
12	.7	1.3	1.7	3.3	4.9	6.6	8.3	9.9	11.6	13.2	16.5	19.8	23.1

TABLE I

PRODUCTION TABLE FOR MODEL B

ANNUAL DEMAND

Q	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	5.8	29.2	58.5	87.7	117	146	175	205	234	263	293	322	351	380	410
3	1.9	9.7	19.5	29.2	39.0	48.7	58.5	68.2	78.0	87.7	97.5	107	117	127	137
4	1.0	4.9	9.7	14.6	19.5	24.4	29.2	34.1	39.0	43.9	48.7	53.6	58.5	63.4	68.2
5	.6	2.9	5.8	8.8	11.7	14.6	17.5	20.5	23.4	26.3	29.2	32.2	35.1	38.0	40.9
6	.4	1.9	3.9	5.8	7.8	9.7	11.7	13.6	15.6	17.6	19.5	21.4	22.4	25.3	27.3

TABLE II

PRODUCTION TABLE FOR MODEL C

ANNUAL DEMAND

Q	1	2	3	4	5	6	7	8	9	10	15	20	25	30	35
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	19.2	38.4	57.5	76.7	95.9	115.1	134	153	172	192	287	383	479	575	671
3	6.4	12.7	19.2	25.6	32.0	38.4	44.7	51.2	57.5	63.9	95.9	127.9	160	192	224
4	3.2	6.4	9.6	12.8	16.0	19.2	22.3	25.6	28.8	32.0	47.9	63.9	80.0	95.9	112
5	1.9	3.8	5.8	7.7	9.6	11.5	13.4	15.3	17.3	19.2	28.8	38.4	47.9	57.5	67.1
6	1.3	2.6	3.8	5.1	6.4	7.7	8.9	10.2	11.5	12.8	19.2	25.6	32.0	38.4	44.7
7	.9	1.8	2.7	3.6	4.6	5.5	6.4	7.3	8.2	9.1	13.7	18.3	22.8	27.4	32.0
8	.7	1.4	2.1	2.7	3.4	4.1	4.8	5.5	6.2	6.8	10.3	13.7	17.1	20.6	24.0

TABLE III

PRODUCTION TABLE FOR MODEL D

ANNUAL DEMAND

Q	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	29.1	43.6	58.2	72.7	87.3	102	116	131	146	160	175	189	204	218	233
3	9.7	14.5	19.4	24.2	29.1	33.9	38.8	43.6	48.5	53.3	58.2	63.1	67.9	72.7	77.6
4	4.8	7.3	9.7	12.1	14.6	17.0	19.4	21.8	24.2	26.7	29.1	31.5	33.9	36.4	38.8
5	2.9	4.4	5.8	7.2	8.7	10.2	11.6	13.1	14.6	16.0	17.5	18.9	20.4	21.8	23.3
6	1.9	2.9	3.9	4.8	5.8	6.8	7.7	8.7	9.7	10.7	11.6	12.6	13.6	14.5	15.5

TABLE IV

Attention must be called to the fact that the unit costs are constant and not a function of the number produced in each production run. In effect this ignores the fact that learning takes place during multiple unit production and gives a smaller or more conservative economic production quantity. It would be a simple matter, however, to account for learning if it were felt that one knew the learning rate. For example, under the constant learning rate discussed previously, one would modify the entries in the matrix by a multiplier as follows:

$$\frac{I_U}{I_L} = \frac{\frac{2A\lambda}{C[Q(Q-1)]}}{\frac{2A\lambda}{L_Q[Q(Q-1)]}} = \frac{L_Q}{C}$$

or

$$I_L = I_U \frac{C}{L_Q}$$

where: L_Q is the average unit cost when producing Q items
 I_L is the holding cost rate considering learning
 I_U is the holding cost rate ignoring learning
which is shown in the following matrices.

The simplification of ignoring learning rates was made for the reasons: 1) Company personnel will be better able to update the matrices as changes or refinements in model parameters are made; 2) the "no-learning" gave more conservative production decisions which conform with previously discussed Company policy of reducing inventory investment; and 3) it was felt that the true learning function was not known.

F. STOCKING POLICY

The present stocking policy for all produced equipments of The Company allows stockouts. As has been discussed earlier, customers anticipate a normal production and shipping time delay after submitting their orders. Therefore, stockout costs during the period have been ignored in the determination of the production quantities. Although stockout costs were not considered, it must be acknowledged that they do exist and their cost is in fact greater than zero. One can infer that inventory stock levels should be revised (thus reducing stockouts) to minimize the total costs related to production inventory operations.

The recommended production policy for each model is to produce at the time the order is received either the quantity, Q , determined for that model, or produce the quantity ordered less the amount on hand, whichever is greater.

G. COST COMPARISON

It cannot be shown that the recommended stocking policy is optimal. However, to establish the worthiness of the production quantity recommendations provided herein, a twelve month comparison was made between the costs incurred if policies of The Company were followed and the costs incurred if the recommendations of this paper were followed.

Annual demand estimates which were available during the sample period were used to determine production quantities.

The annual sales (or demand estimates) were updated quarterly thus allowing production guidelines, Q , to also be updated. Utilizing the production quantity, Q , for the current quarter, production of items was initiated upon the occurrence of the first demand. The annual holding cost rate, I , was assumed to be 0.33. This rate is considered to be an upper bound on the parameter and was selected to demonstrate the effectiveness of this model even under such an adverse environment. The items were reduced from inventory as actual sales, as indicated by shipping data, occurred. When the inventory became zero and a demand was unfilled (i.e. a backorder existed) the recommended production quantity (or a minimum integer multiple of this quantity) was produced to at least meet all current demands. As an example, suppose an inventory of five existed, and based on the recent estimates of annual demand the recommended production quantity was three. If a demand of nine were received, the five in inventory would be issued and six would be produced to meet the outstanding demand of four. The inventory remaining after this transaction would be two ($5-9+6$). However, only one set-up cost would be incurred since only one production run was experienced.

Accumulating holding costs over the year and adding set-up costs for each production run, the total inventory costs for each model was determined. This was compared to the cost incurred as a result of the current Company policy of making the quantity demanded upon receipt of the demand (thus

eliminating any holding costs). It must be noted here that the single exception to the current general Company policy is for the production of model A when The Company always produces in batches of twenty-five. This exception is considered in the cost computations below. The results of this comparison immediately follow:

	Actual Demand	<u>Recommended Policy</u>			<u>Company Policy</u>		
		<u>Holding</u> Cost	<u>Set-up</u> Cost	<u>Total</u> Cost	<u>Holding</u> Cost	<u>Set-up</u> Cost	<u>Total</u> Cost
Model A	77	\$6680	\$12000	\$18680	\$28404	\$ 4800	\$33204
Model B	16	\$ 280	\$ 170	\$ 450	0	\$ 227	\$ 227
Model C	14	\$6600	\$ 9360	\$15960	0	\$16380	\$16380
Model D	7	\$7525	\$ 9000	<u>\$16525</u>	0	\$18000	<u>\$18000</u>
Total Cost				\$51615	Total Cost \$67811		

With the exception of Model B, the decisions recommended resulted in significant savings in costs (a total of 24% annually) over those actually incurred using The Company's policy. If backorder costs were considered in this comparison, the savings would have been even greater. Likewise if the value of I in the comparison were reduced to a level which is probably more realistic, the resultant savings would have been even more significant.

The apparent failure of the recommended production policy to reduce inventory costs for Model B was due to a very erratic demand over the period, and the fact the sales estimates were very poor. Since the production quantity depends heavily on the forecasted values, these results suffered in the comparison for Model B. Using these sales estimates caused an

unnecessary inventory buildup and the low and erratic realization of actual sales resulted in a surplus of stock. This is a very good example of the importance of sales estimates as used in this model and as earlier discussed in this paper. This indicates that perhaps one should calculate λ as four times the current quarter's demand instead of using the sum of the next four quarter's demand. Had this been done, the example just examined would have displayed even more savings. It is felt that these cost savings fully support the recommendations made in this paper.

H. DISCUSSION OF MODEL WEAKNESSES

Several weaknesses in parameter estimation have already been mentioned in developing the model for production equipment inventory decisions. It seems appropriate to proffer some suggestions for making improvements in these parameters.

The parameters having least credibility are those concerning set-up costs, unit costs, and learning rates. Several avenues of approach toward better estimating them are available.

The total cost, T , of the production run which produces a quantity, Q , is given by:

$$T = QL_Q C + A$$

where $L_Q = (LR)^{\log_2(Q)}$ and LR is the unknown learning rate. The equation is in three unknowns, C , A , and LR . If it were possible to achieve exact data as to the total cost, T , of each run, three production runs of three separate production

quantities could be made and the three equations solved for the unknowns. Since exact data accumulation is not expected, particularly with the stochastic nature of the cost itself, other alternatives are considered more practical.

The Industrial Engineering Division could compile a study covering detailed production functions for every facet of the production process for the four equipments. From this information, each action in the process could be assigned "set-up" or "production" phases of the operation. By using already established labor hourly costs multiplied by set-up time hours, the applicable set-up costs could then be estimated with a higher degree of accuracy. Using existing total cost data for single and multiple item production runs, unit costs and learning rates could be more closely estimated.

The third method of determining these parameters assumes a known learning rate. Several production runs of various quantities are made and their total costs, T , recorded. For each pair of production run costs, determine the value of A and C from:

$$A = T - QL_Q C$$
$$C = \frac{T - A}{QL_Q}$$

One thus obtains $n(n-1)$ values for A and C (where n is the number of production runs). Determine the variance of both A and C . Repeat this procedure for several feasible learning rates finally choosing that learning rate and mean values of A and C for which the variances of A and C are minimum.

III. DEVELOPING A POLICY FOR RAW MATERIAL INVENTORY MANAGEMENT

A. MATERIAL CATEGORIES

To support both the production operation and sales of spare parts, a raw material inventory of approximately 11,000 line items is maintained. In order to attempt to better concentrate management attention, The Company has established three material categories and related stocking policies.

1. Items whose Unit Costs are Less than One Dollar

These items are stocked without stock record cards, but are maintained in stock on a "two-bin" or "low level" system. That is, when the stock reaches a predetermined low level (generally signified by the opening of a specially marked box or set of boxes containing the remaining items in stock) an order to raise the item's inventory position to its predetermined high level, is initiated. The high level is reviewed periodically by the stock control supervisor. This policy, commonly known as an (S,s) policy, has been widely investigated and found to work well in many situations.

2. Items whose Unit Cost Range from One to Five Dollars

Under current policy stock record cards are maintained for these items. Orders are initiated when the stock level falls below a predetermined low limit and the quantity ordered is that amount which raises the inventory position to a predetermined high level. The high and low levels were

determined subjectively after considering recently recorded demand so as to minimize stock-outs while keeping inventory levels to within "reasonable" limits.

3. Items whose Unit Cost is Greater Than Five Dollars

Although stock record cards are maintained for these items, the items are generally not kept in stock. When an item is required, it is ordered only in the amount required to meet the current need. In a relatively few cases, as when demands are very high, the items are stocked as mid-range priced items (i.e. inventory levels are maintained between high and low limits).

B. BACKGROUND OF MODEL DEVELOPMENT

A deterministic model like that used to establish production quantities was also used to establish order quantities for each of the three categories of raw material. It is recognized that the demand is not deterministic, but random; however, attempts to determine the distribution of these demands was unsuccessful. The data showed that items were usually demanded in batches. This led to a test that the demands were distributed as a compound Poisson. A Chi-squared goodness-of-fit test indicated strongly that the customer inter-arrival time was not exponentially distributed. As a simplifying assumption order quantities were calculated based on deterministic demand, but reorder levels were dependent upon the stockastic nature of the actual demand history.

C. MODEL PARAMETERS

It was felt that an accurate figure for the holding cost rate for production items could not be obtained for lack of information primarily about obsolescence and deterioration. However, these two factors were not as important when applied to the raw material inventory. A figure of 14.5% per year per dollar of inventory cost was determined. This rate consisted of a 6% charge imposed by the parent company; 1/2% for warehouse rental; 2.7% for salary and fringe benefits of employees connected with maintenance and operation of the inventory function, 3% for taxes on the inventory itself, and an additional 2.3% The Company feels it should consider as a "cost of money" charge over and above the 6% charged by the parent company. Insurance is paid by the parent company and is not considered a function of raw material on-hand inventory value. Intangibles such as pilferage, obsolescence and deterioration were not directly considered in determining holding cost rate.

Purchase cost, A, was found to be \$16.00 per order. This was computed from the costs of material and services (including telephone service) used in the purchasing operation, and from the wages and benefits paid to personnel of the purchasing division and to those in the accounting division concerned with processing and paying for those procurements. The total of these charges were approximately \$8000 for an average month and an average months orders numbered

512. Thus:

$$A = \frac{\$8000}{515} \approx \$16.$$

It appears that both the holding cost rate and the procurement costs are lower than what is actually experienced at other similar industries. Note that the expression for the optimum order quantity derived from the simple model $[2\lambda A/IC]^{1/2}$, depends on parameters A and I only through ratio A/I. Although the values obtained as estimates of these parameters both seem to be smaller than those anticipated, it is felt that the errors of the estimates are not critical since the magnitude of the ratio seems to be relatively good.

The parameters of unit cost, C, and annual demand, λ , must also be considered. The information on the stock record cards (using current Company posting procedures) will always reflect the last unit cost. Any large changes in this value will be immediately evident and require a recalculation of the order values (see next section). Changes in annual demand may also occur. Like the changes in unit cost, this information is also on the stock record card. It is not displayed directly but must be computed periodically. By considering the changes in these two parameters, the model will readjust itself to current conditions.

D. ORDER QUANTITIES

A matrix shown on the following page was constructed based on the A/I ratio discussed in section C. The matrix

λ

UNIT COST (\$)

DEMAND	.01	.10	.25	.50	1	2	4	5	8	10	15	20	30	40	50	75	100
3	257	81	51	36	26	18	13	11	9	8	7	6	5	4	4	3	3
4	297	94	59	42	30	21	15	13	10	9	7	6	6	4	4	3	3
6	364	114	73	52	36	25	18	15	13	12	9	7	6	6	4	4	3
9	446	141	89	62	45	31	22	19	16	13	12	10	7	7	6	4	4
12	514	162	103	73	52	36	25	24	18	16	13	10	9	7	7	6	4
15	575	181	114	82	58	40	28	25	21	18	15	13	10	9	7	6	6
18	630	199	126	89	62	45	31	28	22	19	16	13	12	10	9	7	6
21	680	215	137	97	68	48	34	30	24	21	18	15	12	10	9	7	7
24	728	230	146	103	73	52	37	33	25	22	19	16	13	12	10	9	7
30	814	257	163	114	82	58	40	36	27	25	21	18	15	13	12	9	7
36	891	282	178	126	89	62	45	40	31	28	22	19	16	13	13	10	9
48	1029	325	206	146	103	73	52	46	36	33	27	22	19	16	15	12	10
60	1151	364	230	163	114	82	58	52	40	37	30	25	21	18	16	13	12
72	1261	398	253	178	126	89	62	56	45	40	33	28	22	19	18	15	12
84	1362	431	272	193	137	97	68	61	48	43	36	30	24	21	19	16	13
96	1456	461	291	206	146	103	73	65	52	46	37	33	27	22	21	16	15
108	1543	489	309	218	154	108	77	68	55	49	40	34	28	24	22	18	15
120	1627	514	325	230	163	114	82	73	58	52	42	36	30	25	24	19	16
240	2300	728	461	325	230	163	114	103	82	73	59	52	42	36	33	27	22
600	3640	1151	728	514	364	257	181	163	129	114	94	82	67	58	52	42	36

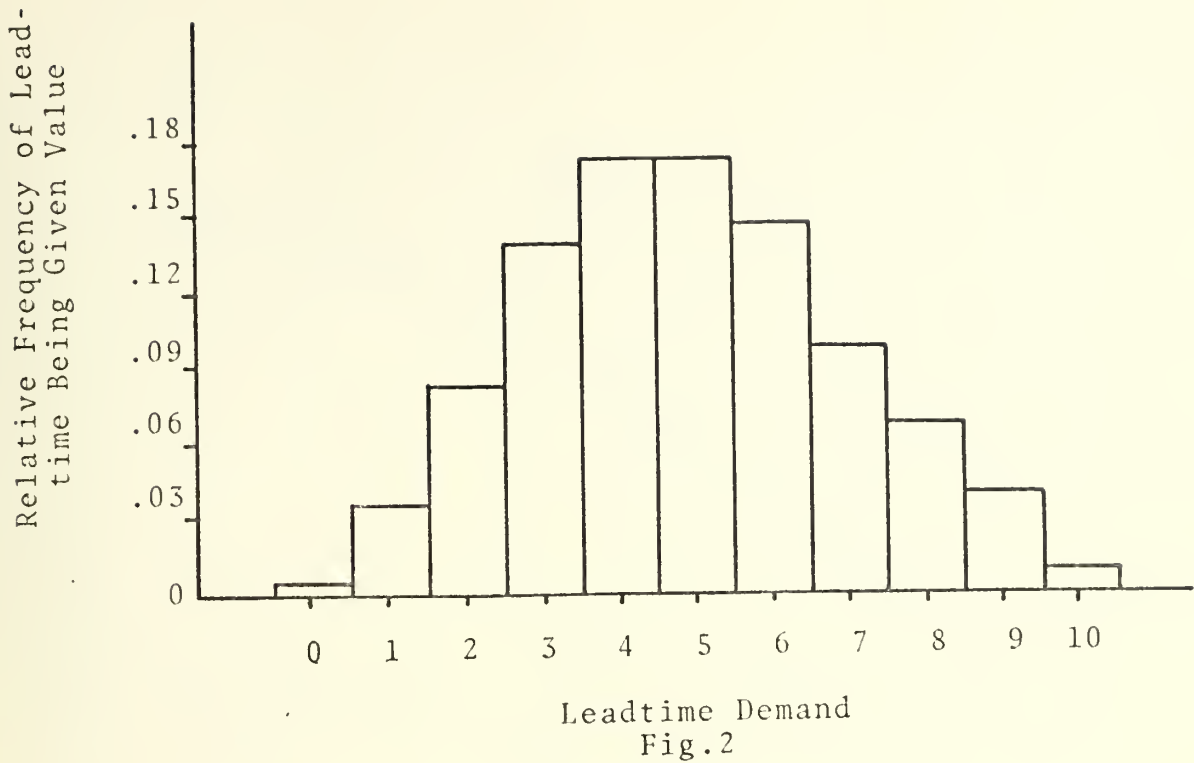
ORDER QUANTITIES

TABLE V

shows the economic order quantities (EOQ) for the range of unit costs and annual demands experienced by The Company.

E. REORDER LEVELS

Although a method for determining the order quantities, assuming deterministic demands and no stockout costs has been recommended, one must not ignore either the random nature of the demand process or the stockout costs. These are both considered in the determination of the reorder levels. To account for these factors, the distribution of demand during leadtime for each item must be considered. Define the safety level for an item to be the expected stock on hand when a shipment arrives. Then to reduce the probability of a stockout, it would be necessary to increase the safety level and in this manner provide protection against unanticipated higher demands. As the critical interval of time is the period between the placing of an order and the receipt of that order, it is the distribution of leadtime demand that must be considered. Many studies have shown that a Normal distribution for leadtime demand (especially in the case of high demand items) is a good approximation of the distribution usually experienced in these cases. However, for illustration purposes, consider the empirical distribution of leadtime demand for a representative item shown in figure 2. From this empirical distribution, the expected leadtime demand is found to be five units. Therefore, if an order is placed when the stock on hand reaches five, the safety



level is zero and the probability of a stockout occurring, $P(\text{OUT})$, would be .56, that is, the leadtime demand would exceed five with probability .56. Similarly, for a reorder level of ten (a safety level of five) the probability of being out of stock would fall to approximately $P(\text{OUT}) = .03$. For the above example, the probability of incurring a stockout for various safety levels is shown in fig. 3.

As a unit change in safety level is made, a change in the inventory holding costs equal to IC is incurred. These changes are shown in fig. 4 for items with several unit costs. Thus it is recommended that management balance the desired service level (i.e. the probability of incurring a stockout) with the increased holding cost in determining

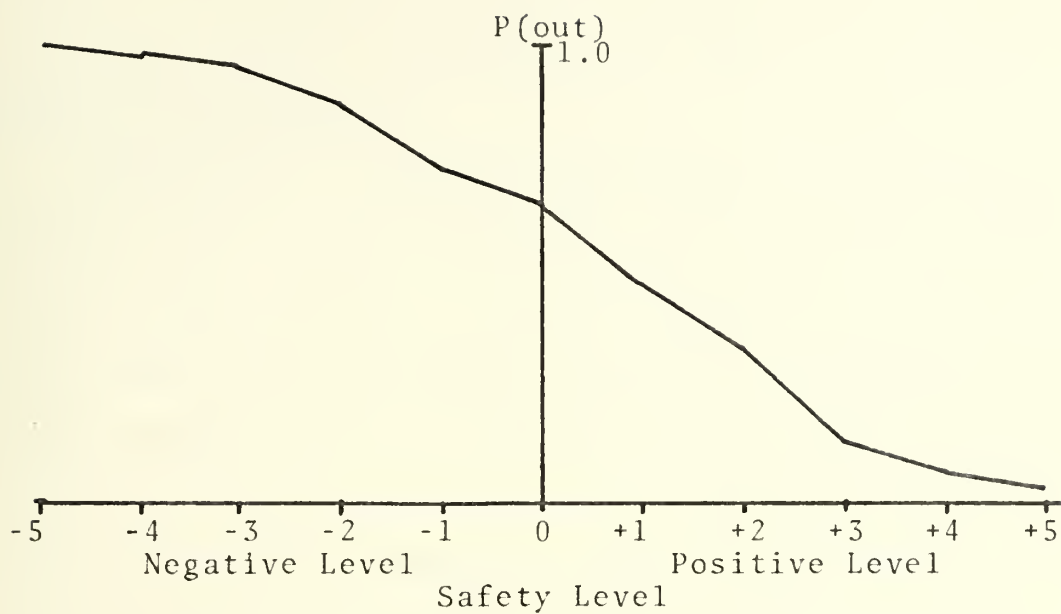


Fig. 3

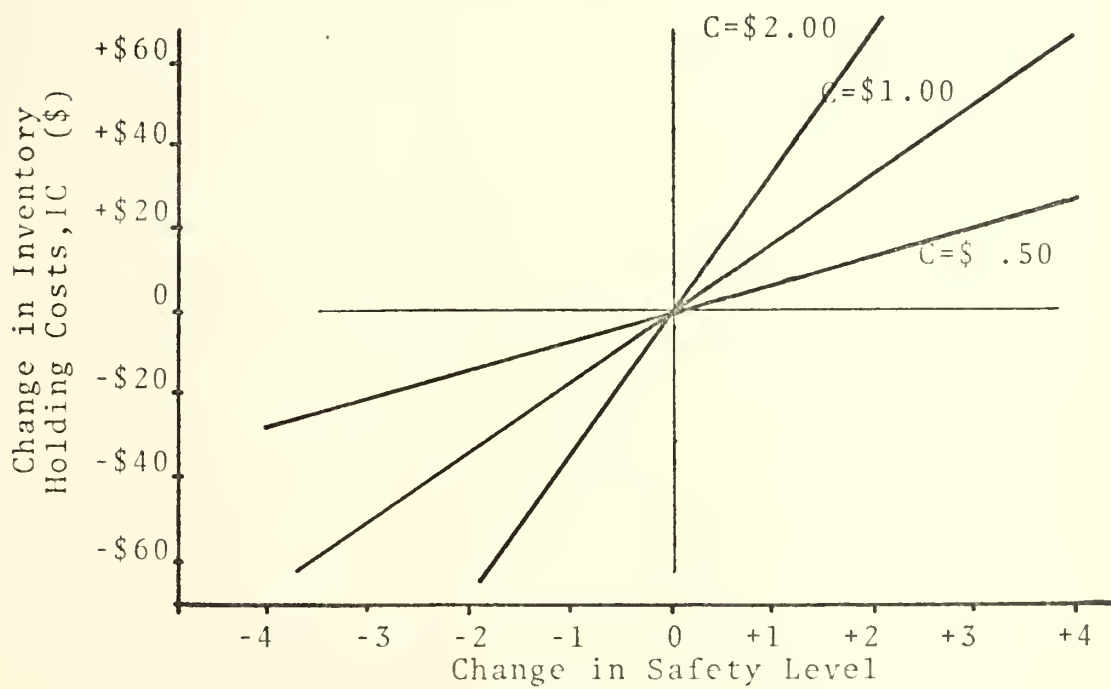


Fig. 4

safety stock. It should be noted that since the unit increase in holding cost per unit increase in safety level equals IC , the more expensive the item is, the smaller the safety level should be.

Another way to view the importance of balancing the extra holding cost with the increase in service is to consider the extra holding cost as a stockout cost, for it is an extra cost that is paid to reduce stockouts. Therefore an imputed stockout cost can be determined for any given safety level by comparing the total holding cost for a given safety level, S , with the total holding cost when a safety level of zero is maintained. The differences between the two costs is given by ICS . These imputed stockout costs are shown in fig. 4 for the example considered.

[illegible]

C.....SETTING INITIAL VALUES OF THE DECISION VARIABLES

MIN00470
MIN00480
MIN00490
MIN00500
MIN00510
MIN00520
MIN00530
MIN00540
MIN00550
MIN00560
MIN00570
MIN00580
MIN00590
MIN00600
MIN00610
MIN00620
MIN00630
MIN00640
MIN00650
MIN00660
MIN00670
MIN00680
MIN00690
MIN00700
MIN00710
MIN00720
MIN00730
MIN00740
MIN00750
MIN00760
MIN00770
MIN00780
MIN00790
MIN00800
MIN00810
MIN00820
MIN00830
MIN00840
MIN00850
MIN00860
MIN00870
MIN00880
MIN00890
MIN00900
MIN00910
MIN00920
MIN00930
MIN00940

X(1)=4.07
X(5)=12.3
X(9)=3.9
X(13)=6.75
X(17)=7.4
X(21)=7.4
X(2)=0.
X(6)=25.
X(10)=25.0
X(14)=115.
X(18)=126.5
X(22)=126.5
X(3)=0.0
X(7)=0.0
X(11)=0.0
X(15)=0.0
X(19)=0.0
X(23)=0.0
X(4)=0.0
X(8)=3.5
X(12)=0.0
X(16)=0.0
X(20)=0.0
X(24)=0.0
C.....XNV(1) IS THE INVENTORY AT THE START OF PERIOD (1)
C.....BEFORE PRODUCTION DURING THAT PERIOD HAS STARTED

XNV(1)=10.
XNV(2)=26.
XNV(3)=0.
XNV(4)=7.
C.....H(I) IS THE HOLDING COST RATE

H(1)=.33
H(2)=.33
H(3)=.33
H(4)=.33
C.....C(I) IS THE PRODUCTION COST OF EACH OF THE MODELS

C(1)=5500.
C(2)=860.
C(3)=12200.
C(4)=20600.
C.....S(I) IS THE SET-UP COST OF EACH OF THE FOUR MODELS

S(1)=1200.
S(2)=56.8
S(3)=2340.
S(4)=3000.
DO 3001 I=1,4
DO 3002 K=4,20,4

MIN00950
MIN00960
MIN00970
MIN00980
MIN00990
MIN01000
MIN01010

H(I+K)=H(I)
C(I+K)=C(I)
S(I+K)=S(I)
3002 CONTINUE
3001 CALL SDRMIN
STOP
END

```

SUBROUTINE OBJFCT
COMMON X(24),C(24),H(24),S(24),SU(24),XNV(24),D(24),BNIS(24),RIALV
1(24),XMAX(24),XMIN(24),N,MAXTRY,TRIALV
DO 3021 I=5,24
C.....DETERMINING THE INVENTORY AT THE START OF EACH PERIOD
3021 XNV(I)=XNV(I-4)+X(I-4)-D(I-4)
DO 3030 II=1,N
ASSET=XNV(II)+X(II)
BNIS(II)=0
IF(ASSET.LT.D(II)) BNIS(II)=1000000000.
211 IF(X(II).LT.0.0001) GO TO 220
IF(X(II).GE.0.0001) GO TO 221
C.....IF NO ITEMS ARE PRODUCED, NO SET-UP COSTS ARE INCURRED
220 SU(II)=0
GO TO 3030
C.....IF ANY ITEMS ARE PRODUCED, THE SET-UP COST IS INCURRED
221 SU(II)=S(II)
3030 CONTINUE
TRIALV=0
C.....COMPUTING THE INVENTORY COSTS FOR THE FIRST FIVE PERIODS
OF ALL FOUR MODELS
DO 7009 KK=1,20
IF((XNV(KK+4)+D(KK)/2.0).LT.0.00001) GO TO 69
RIALV(KK)=(XNV(KK+4)+D(KK)/2.0)*(H(KK)*.25*C(KK))+SU(KK)+
1BNIS(KK)+C(KK)*X(KK)
GO TO 7009
69 RIALV(KK)=SU(KK)+BNIS(KK)+C(KK)*X(KK)
7009 TRIALV=TRIALV+RIALV(KK)
C.....COMPUTING THE INVENTORY COSTS FOR THE LAST (SIXTH) PERIOD
OF ALL FOUR MODELS
DO 9007 KK=21,N
IF((XNV(KK)+X(KK)/2.0).LT.0.000001) GO TO 669
RIALV(KK)=((XNV(KK)+X(KK)/2.0)*(H(KK)*.25*C(KK))+SU(KK)+BNIS(KK)+
1C(KK)*X(KK)
GO TO 9007
669 RIALV(KK)=SU(KK)+BNIS(KK)+C(KK)*X(KK)
9007 TRIALV=TRIALV+RIALV(KK)
RETURN
END

```

MIN01020
MIN01030
MIN01040
MIN01050
MIN01060
MIN01070
MIN01080
MIN01090
MIN01100
MIN01110
MIN01120
MIN01130
MIN01140
MIN01150
MIN01160
MIN01170
MIN01180
MIN01190
MIN01200
MIN01210
MIN01220
MIN01230
MIN01240
MIN01250
MIN01260
MIN01270
MIN01280
MIN01290
MIN01300
MIN01310
MIN01320
MIN01330
MIN01340
MIN01350
MIN01360
MIN01370
MIN01380
MIN01390
MIN01400


```

C      SUBROUTINE SEARCH DECISION RULE      MINIMIZATION      MIN01410

SUBROUTINE SDRMIN
COMMON X(24),C(24),H(24),S(24),SU(24),XNV(24),D(24),BVIS(24),RIALV
1(24),XMAX(24),XMIN(24),N,MAXTRY,TRIALV
DIMENSION STEP(100),XBEST(100)
C INITIALIZE CONTROL PARAMETERS
MAXABT=10
PCTHI=.5
PCTMED=.25
PCTMIN=1.E-2
STPDEC=.1
STPINC=2.
STPMIN=1.E-10
STPSET=.1
C INITIALIZE COUNTERS
IPAGE=1
LINE=100
NDEC=0
NEVAL=0
NFWDF=0
NFWDO=0
NFWDS=0
NMIN=0
NPAT=0
NPRIOR=0
NPROG=0
NREST=0
NREVF=0
NREVO=0
NREVS=0
C COMPUTE PATTERN MOVE PRINT FREQUENCY
IPRINT=10/N
IF(IPRINT.LT.1)IPRINT=1
C TERMINATE THE SEARCH IF MAXABT(SEARCH RESTART LIMIT)IS EXCEEDED
200 NABORT=NMIN+NPROG
IF(NABORT.GT.MAXABT) GO TO 800
C RESET EXP SEARCH SUCCESS STATUS FLAG + PATTERN MOVE ACCELERATOR
IFLAG=0
ACCEL=2.
C COMPUTE INITIAL STEP SIZE VECTOR STEP(I) + SAVE TRIAL VECTOR X(I)
DO 250 I=1,N
STEP(I)=STEP*(XMAX(I)-XMIN(I))
XBEST(I)=X(I)
C TEST TO INSURE ALL SOLUTION VECTOR COMPONENTS ARE WITHIN BOUNDS
C IF OUTSIDE RESET TO XMAX(I) OR XMIN(I) BOUNDARY
300 DO 350 I=1,N

```



```

350 IF(X(I).GT.XMAX(I)) X(I)=XMAX(I)
C EVALUATE OBJECTIVE FUNCTION + INCREMENT EVALUATION COUNTER
C CALL OBJFCT
C NEVAL=NEVAL+1
C RECORD INITIAL SOLUTION VALUE FOR COMPARISON DURING EXP SEARCH PHASE
C GOODV=TRIALV
C IF INITIAL PASS OF SEARCH INITIALIZE + PRINT INITIAL CONDITIONS
C IF(NEVAL.GT.1) GO TO 400
C PCTDEC=0.
C INITIALIZE WITH INITIAL SOLUTION VALUE (TRIALV)
C BESTV=TRIALV
C FIRSTV=TRIALV
C PRIORV=TRIALV
C PRINT INITIAL CONDITIONS
C WRITE(8,930) IPAGE
C WRITE(8,932)
C WRITE(8,934)
C WRITE(8,936)
C WRITE(8,938)
C WRITE(8,940)
C WRITE(8,942)
C WRITE(8,944)
C WRITE(8,946)
C WRITE(8,948)
C WRITE(8,950)
C WRITE(8,952)
C WRITE(8,954)
C WRITE(8,956)
C WRITE(8,958)
C WRITE(8,960)
C WRITE(8,962)
C WRITE(8,964)
C WRITE(8,966)
C PRINT NEW PAGE HEADING, INITIAL SEARCH VALUES + RETURN TO STMT 400
C JPRINT=1
C GO TO 900
C TERMINATE THE SEARCH IF MAXTRY(OBJFCT EVALUATION LIMIT) IS EXCEEDED
C 400 IF(NEVAL.GT.MAXTRY) GO TO 800
C INITIALIZE MINIMUM STEP SIZE COUNTER
C NSTEP=0
C ..... START EXPLORATORY SEARCH SECTION
C .....

```

```

MIN01870
MIN01880
MIN01890
MIN01900
MIN01910
MIN01920
MIN01930
MIN01940
MIN01950
MIN01960
MIN01970
MIN01980
MIN01990
MIN02000
MIN02010
MIN02020
MIN02030
MIN02040
MIN02050
MIN02060
MIN02070
MIN02080
MIN02090
MIN02100
MIN02110
MIN02120
MIN02130
MIN02140
MIN02150
MIN02160
MIN02170
MIN02180
MIN02190
MIN02200
MIN02210
MIN02220
MIN02230
MIN02240
MIN02250
MIN02260
MIN02270
MIN02280
MIN02290
MIN02300
MIN02310
MIN02320
MIN02330
MIN02340

```



```

C      DO 500 I=1,N
C      IF STEP SIZE IS ZERO OMIT EXP SEARCH FOR THAT COMPONENT
C      IF (STEP(I).EQ.0) GO TO 490
C
C      FORWARD MOVE LOGIC
C      -----
C      COMPUTE X(I) FOR FORWARD MOVE
C      X(I)=X(I)+STEP(I)
C      IF OUTSIDE BOUNDS TRY A REVERSE MOVE
C      IF (X(I).GT.XMAX(I).OR.X(I).LT.XMIN(I)) GO TO 410
C      EVALUATE OBJECTIVE FUNCTION + INCREMENT EVALUATION COUNTER
C      CALL OBJECT
C      NEVAL=NEVAL+1
C      IF NEW POINT IS NOT BETTER TRY A REVERSE MOVE
C      IF (TRIALV.GE.GOODV) GO TO 420
C      GOODV=TRIALV
C      NFWDS=NFWDS+1
C      IF LAST EXP SEARCH WAS ALSO SUCCESSFUL THEN INCREASE STEP SIZE
C      IF (IFLAG.GT.0) STEP(I)=STEP(I)
C      GO TO 500
C
C      REVERSE MOVE LOGIC
C      -----
C
C      INCREMENT COUNTERS
C      410 NFWDO=NFWDO+1
C      GO TO 430
C      420 NFWDF=NFWDF+1
C      COMPUTE X(I) FOR REVERSE MOVE
C      430 X(I)=X(I)-2.*STEP(I)
C      IF OUTSIDE BOUNDS RESTORE X(I) + REDUCE STEP SIZE
C      IF (X(I).GT.XMAX(I).OR.X(I).LT.XMIN(I)) GO TO 440
C      EVALUATE OBJECTIVE FUNCTION + INCREMENT EVALUATION COUNTER
C      CALL OBJECT
C      NEVAL=NEVAL+1
C      IF NEW POINT IS NOT BETTER RESTORE X(I) + REDUCE STEP SIZE
C      IF (TRIALV.GT.GOODV) GO TO 450
C      GOODV=TRIALV
C      REVERSE STEP DIRECTION
C      STEP(I)=-STEP(I)
C      NREVS=NREVS+1
C      GO TO 500
C
C      RESTORE X(I) + REDUCE STEP LOGIC
C      -----
C      INCREMENT COUNTERS
C      440 NREVO=NREVO+1

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450 GO TO 460
C NREVF=NREVF+1
C RESTORE X(I) TO VALUE PRIOR TO FORWARD MOVE
460 X(I)=X(I)+STEP(I)
C REDUCE STEP SIZE
STEP(I)=STEPDEC*STEP(I)
C TEST STEP SIZE - RESTORE TO MIN VALUE(STPMIN) IF BELOW MINIMUM
IF(ABS(STEP(I)).GE.STPMIN) GO TO 500
IF(STEP(I).GE.0.) STEP(I)=STPMIN
IF(STEP(I).LT.0.) STEP(I)=-STPMIN
C INCREMENT MINIMUM STEP SIZE COUNTERS
490 NREST=NREST+1
500 NSTEP=NSTEP+1
510 CONTINUE
C NOTE:GOODV IS THE BEST VALUE FOUND DURING THE EXP SEARCH PHASE
C THE CORRESPONDING SOLUTION VECTOR IS X(I)
C
C .....
C END OF EXPLORATORY SEARCH SECTION
C .....
C TEST FOR SUCCESS OR FAILURE OF EXPLORATORY SEARCH
IF(GOODV.LT.BESTV) GO TO 700
C
C .....
C EXPLORATORY SEARCH IS A FAILURE
C -----
C RESTORE TRIAL VECTOR X(I) TO BEST PRIOR VALUE
DO 650 I=1,N
X(I)=XBEST(I)
C IF ALL COMPONENTS OF STEP(I) ARE AT MIN INCREMENT COUNTER AND
C RESTART SEARCH USING INITIAL STEP SIZE VECTOR
IF(NSTEP.LT.N) GO TO 660
C TEST FOR NEW PAGE, PRINT SEARCH DATA + GO TO SIMT 200 TO RESTART
NMIN=NMIN+1
JPRINT=2
GO TO 900
C RESET VARIABLES, INCREMENT COUNTER + MAKE ANOTHER EXP SEARCH
660 GOODV=BESTV
IFLAG=0
NDEC=NDEC+1
GO TO 400
C EXPLORATORY SEARCH IS A SUCCESS
C -----
C FIND PCTDEC-THE PERCENT DECREASE/EVALUATION SINCE LAST SUCCESSFUL
C EXPLORATORY SEARCH + RESET VARIABLES
700 BESTV=GOODV

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XX=NEVAL-NPRIOR
PCTDEC=A3S(100.0*(PRIORV-GOODV)/(PRIORV*XX))
PRIORV=GOODV
NPRIOR=NEVAL
C TEST FOR SATISFACTORY PROGRESS DEFINED BY PCTMIN
IF(PCTDEC-GE.PCTMIN) GO TO 720
C
C PROGRESS IS SATISFACTORY -- SAVE SOLUTION VECTOR, PRINT STATUS +
RESTART SEARCH USING INITIAL STEP SIZE VECTOR
NPRGG=NPRG+1
DO 710 I=1,N
  XBEST(I)=X(I)
710 C TEST FOR NEW PAGE, PRINT SEARCH DATA + GO TO STMT 200 TO RESTART
  JPRINT=2
  GO TO 900
C PROGRESS IS SATISFACTORY -- INVOKE PATTERN MOVE LOGIC
C FIND PATTERN MOVE ACCELERATION FACTOR (ACCEL) FROM ADAPTIVE LOGIC
720 IF(PCTDEC-LE.PCTMED) ACCEL=ACCEL+0.10
IF(PCTDEC-LE.PCTHI) ACCEL=ACCEL+0.05
IF(ACCEL-GE.3.5) ACCEL=2.2
C SAVE CURRENT SOLUTION VECTOR IN XBEST(I) + PLACE NEW PATTERN
C MOVE VECTOR IN X(I) FOR EVALUATION
DO 750 I=1,N
  XX=XBEST(I)
  XBEST(I)=X(I)
  X(I)=XX+ACCEL*(X(I)-XX)
750 C SET EXP SEARCH SUCCESS FLAG + INCREMENT COUNTER
  IFLAG=1
  NPAT=NPAT+1
  JPRINT=3
C TEST PRINT CONTROL PARAMETER PRINT PARAMETER(IPRINT) + PRINT LINE
C INFORMATION IF NPAT IS AN EVEN MULTIPLE OF IPRINT
C RETURN TO STMT 300 AFTER PRINTING STATUS INFO
IF(MOD(NPAT,IPRINT)) 300,900,300
C TEST FOR NEW PAGE, PRINT LINE OF DATA + RETURN TO PRIOR STMT
C -----
900 IF(LINE-LE.40) GO TO 901
IF(JPRINT-NE.1) WRITE(8,990)
C WRITE NEW PAGE HEADING
  IPAGE=IPAGE+1
  LINE=0
  WRITE(8,930) IPAGE
  WRITE(8,990)
  WRITE(8,991)
  WRITE(8,990)
  WRITE(8,992)
  WRITE(8,993)
  WRITE(8,990)

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C      WRITE LINE OF STATUS INFO
901    WRITE(8,995) NEVAL,BESTV,NPAT,NDEC,NMIN,NPROG,PCTDEC,NFWD0,NFWD5,
      1 NFWD0,NREVO,NREVS,NREVF,NREST
      LINE=LINE+1
      GO TO (400,200,300),JPRINT
C
C      SEARCH TERMINATION - RESET X(I) + PRINT TERMINATION DATA
C-----
800    DO 810 I=1,N
810    X(I)=XBEST(I)
      WRITE(8,995) NEVAL,BESTV,NPAT,NDEC,NMIN,NPROG,PCTDEC,NFWD0,NFWD5,
      1 NFWD0,NREVO,NREVS,NREVF,NREST
      WRITE(8,990)
      IPAGE=IPAGE+1
      WRITE(8,930) IPAGE
      WRITE(8,970)
      WRITE(8,972) NEVAL
      WRITE(8,974) =IRSTV
      WRITE(8,976) BESTV
      WRITE(6,976) BESTV
      XX=NEVAL
      PCTDEC=ABS(100.0*(FIRSTV-BESTV)/FIRSTV)
      WRITE(8,977) PCTDEC
      PCTDEC=PCTDEC/XX
      WRITE(8,978) PCTDEC
      WRITE(8,980) (XBEST(I),I=1,N)
      WRITE(6,980) (XBEST(I),I=1,N)
      WRITE(8,982) (STEP(I),I=1,N)
C
      FORMAT(1H1,34X,'* * * * * A D A P T I V E P A T T E R N S E A R
1C H * * * * * I N I T I A L C O N D I T I O N S * * * * * )
932    FORMAT(5X,'NO OF INDEPENDENT VARIABLES',47X,I10)
934    FORMAT(5X,'MAX NO OF OBJECTIVE FUNCTION EVALUATIONS',34X,I10)
936    FORMAT(5X,'MAX NO OF RESTARTS AFTER STEP SIZE OR UNSAT PROGRESS AB
938    ORT',16X,I10)
940    FORMAT(5X,'STEP SIZE MULTIPLIER - INITIAL START',36X,E10.3)
942    FORMAT(5X,'STEP SIZE MULTIPLIER - FWD MOVE SUCCESS FOLLOWING EXP
944    LEARCH SUCCESS',6X,E10.3)
944    FORMAT(5X,'STEP SIZE MULTIPLIER - FORWARD + REVERSE MOVE FAILURE',
1 21X,E10.3)
946    FORMAT(5X,'MIN STEP SIZE FOR ALL INDEPENDENT VARIABLES',31X,E10.3)
948    FORMAT(5X,'UNSAT PROGRESS ABORT (MIN PERCENT IMPROVEMENT PER EVALU
1ATION',13X,E10.3)
950    FORMAT(5X,'PATTERN MOVE ACCELERATOR THRESHOLD - LOW/MED PCT PER EV
1ALUATION',11X,E10.3)
952    FORMAT(5X,'PATTERN MOVE ACCELERATOR THRESHOLD - MED/HI PCT PER EV

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LIST OF REGERENCES

1. Hadley, G. and Whitin, T. M., Analysis of Inventory Systems, Prentice-Hall, 1963.
2. Buffa, E. S. and Taubert, W.H., Production-Inventory Systems: Planning and Control, Richard D. Irwin, Inc., 1972.

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KEY WORDS

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LINK B

LINK C

ROLE

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ROLE

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Inventory Policies

Inventory Model

Stock Level

Search Routine

Search Decision Rule

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